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HARDENED AIRCRAFT SHELTER TEST PROGRAM

BY MICHAEL M. SWISDAK, JR.

RESEARCH AND TECHNOLOGY DEPARTMENT
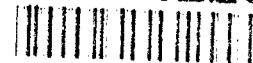
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Dahlgren, Virginia 22448-5000 • Silver Spring, Maryland 20903-5000

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FOREWORD

This work was sponsored by several member nations of the NATO AC/258 Group of Experts on the Safety Aspects of Explosives and Ammunition in Storage and Transport. Specifically, the author would like to acknowledge the support of the following countries: United States, United Kingdom, Norway, Denmark, Spain, Italy, and the Netherlands.

This work represented a team effort. The model was constructed and fielded by personnel from the New Mexico Institute of Mining Technology (NMIMT), TERA Group. Their effort was directed by Mr. Kent Harvey. Statistical analysis of the debris samples was performed by Mr. Tyrone Till, also of NMIMT/TERA. Mr. Verence Moore of the Naval Surface Warfare Center (NAVSWC) directed the field testing and supervised the debris collection effort. Mr. Paul Montanaro of NAVSWC assisted in the computer processing of all of the debris data. Technical direction was provided by Drs. Chester Canada and Jerry Ward of the Department of Defense Explosives Safety Board.

Approved by

WILLIAM H. BOHLI, Head
Energetic Materials Division

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ABSTRACT

Operation DISTANT RUNNER produced data on the size and distribution of both airblast and debris produced by the detonation of 4500 kilograms of high explosive inside a Third Generation Hardened Aircraft Shelter. DISTANT RUNNER also produced data on the fragment/debris hazard ranges which are associated with detonations inside the shelter. After the full-scale tests were completed, that event was modeled at two scales 1:10 and 1:4. These structures used detailed geometric modeling of both the rebar and the aggregate with which the reinforced structure was built. The concrete mixture, however, was modeled for the full-scale compressive strength.

The 1:10 size model appeared to behave as if it were more like a 1:7 scale model. This appeared in the airblast, the size and distribution of the debris, and the hazard ranges produced by the debris. Because of this, testing at a larger scale was undertaken.

This report will present the results of breakup and debris throw for a quarter-scale shelter. Results obtained from all three scales will also be compared. For the structure modeled in these tests and with the decisions which were made about the details of the modeling used, the apparent scale factor (as determined from the breakup of the structure) differs from the design scale factor. As the scale size becomes larger (i.e., smaller models), the differences between design and apparent scale factor increases.

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CHAPTER 1

INTRODUCTION

BACKGROUND

During August through September 1981, Field Command, Defense Nuclear Agency (FC/DNA) conducted a five-event, high explosive test series at White Sands Missile Range, New Mexico. This test series, DISTANT RUNNER, was part of the Defense Nuclear Agency's Theatre Nuclear Forces Survivability, Security, and Safety Program. Event 4 of that series exposed one hardened aircraft shelter (HAS) to an internal pressure/fragmentation loading generated by the simultaneous detonation of 12 MK 82 General Purpose Bombs (net explosive weight (NEW) 1040 kg (2292 pounds) of tritonal) inside the closed shelter. Event 5 exposed another shelter to an internal pressure/fragmentation loading generated by the simultaneous detonation of 48 MK 82 General Purpose Bombs (NEW 4159 kg (9168 pounds) of tritonal) inside the closed shelter. A detailed description of the DISTANT RUNNER Program is found in References 1 to 5.

Because of the scope and completeness of the data generated during the DISTANT RUNNER Series, it was felt that this was an ideal opportunity to investigate/validate the use of affordable models for the breakup of reinforced concrete structures subjected to internal detonations. Five small-scale (1/10) replica models were built and tested. Event 5 of DISTANT RUNNER was the prototype for all of these 1/10-scale models. The data generated included structural breakup, debris distributions (mass and areal density), internal and external airblast, and full-scale debris hazard range. This effort is described in References 6 and 7.

Analysis of the 1/10-scale results (airblast and debris size) (reported in Reference 6) indicates that the structure behaved as if it were larger than it actually was. That is, the data indicate that it behaved more like a 1/6.586 scale rather than a 1/10 scale. Reference 6 postulated several possible reasons for this difference in breakup. These included: (1) concrete strength, (2) use of welded wire mesh instead of rebars, and (3) scaling of the surface energy of the concrete.

Because of the questions that grew out of the analysis of the 1/10-scale data, it was proposed that a further series of experiments at a larger scale (approaching 1/3 to 1/4) be undertaken. This program was to include developmental "slab" tests at various scales before a full model (at a scale to be determined) was built. Because of funding constraints, it was decided to jump directly to the larger model test, omitting the intermediate "slab" tests which were to be used to better describe the concrete breakup, shape, and mass distributions as a function of scale. After investigation, it was decided that the most economical scale (from the standpoint of the availability of materials) was 1/4-scale. In 1990, one 1/4-scale model aircraft shelter was constructed at the New Mexico Institute of Mining Technology (NMIMT), Socorro, New Mexico. Twenty-nine days after the final concrete pour (exhaust port), the model was tested. Reference 8 describes the NMIMT effort in model construction and data collection.

MODEL PHILOSOPHY

The 1/10-scale trials were designed to model both the external shots as well as Event 5 of DISTANT RUNNER. In addition, a mass model of an aircraft was included inside each shelter. Each MK 82 bomb and its location was also modeled. Internal and external airblast were measured on each shot. After this test series was completed, it was the consensus that the pre-conditioning shots (external airblast events) did not contribute to the strength (or weakness) of the model and could be eliminated from any further testing effort. Moreover, the mass model of the airplane did not seem to contribute to shelter response or to the external debris (only small amounts of material attributable to the airplane model was located outside the shelter). As a result, for the 1/4-scale test, no airplane model was included.

CHAPTER 2

QUARTER-SCALE MODEL DETAILS

BOMBLET CONSTRUCTION/LOCATION

The total NEW on DISTANT RUNNER Event 5 was 9,168 pounds—contained in 48 tritonal-loaded MK 82 bombs. When the NEW is calculated for 1/4-scale, it is 143.25 pounds of tritonal. It was decided to substitute Composition C-4 for the tritonal. When the TNT equivalences are taken into account, approximately 130 to 140 pounds of C-4 are required, depending upon the TNT equivalence selected. Each bomb case was simulated by iron pipe with nominal outer diameter 2.625 inches, inner diameter 2.386 inches, and length 13.5 inches. A 0.375-inch end cap was welded on one end. The total explosive weight (including C-4 explosive and the C3 DETASHEET used to initiate it) was 137.08 pounds. All bomblets were initiated simultaneously, using identical lengths of NONEL and detonating cord.

Figures 2-1 and 2-2 show the locations of each bomblet stack.

CONSTRUCTION DETAILS

Details of the materials and construction of the 1/4-scale model are given in Reference 8. Some of the pertinent details will be summarized here.

The shelter was constructed using 1/4-scale reinforcing bar which was welded into mats of the appropriate diameter (0.207 inch and 0.120 inch) and spacing. The concrete mix used for the structure was scaled from the DISTANT RUNNER mix, with adjustments made for availability of materials and producibility. Test specimens of all concrete mixes were taken and compressive strengths as a function of cure time were determined. All were near or exceeded 4000 psi at the time of the test. The results of these tests are presented in Reference 8.

The double-corrugated liner material was not readily available. A single manufacturer was located and the material was manufactured to the appropriate dimensions.

The blast deflector design was scaled up from the 1/10-scale models, rather than scaled down from the full scale. At the time of the 1/10-scale tests, it was decided that this simplification would not affect the quality of the results and would greatly simplify construction, thereby reducing costs.

The floor was joined to the walls of the structure in the same manner as was done on the 1/10-scale models. This has proven to be a point of concern. After discussions with the Department of Defense Explosives Safety Board (DDESB), it was decided that the 1/4-scale test should model the 1/10-scale tests, rather than the full-scale event. Several different schemes have been used in prototype structures to

join the walls of the shelter to the floor slab. One of these where the walls are lightly tied to the floor was modeled on both the 1/10-scale and the 1/4-scale tests.

Figure 2-3 is a series of photographs taken before the event.

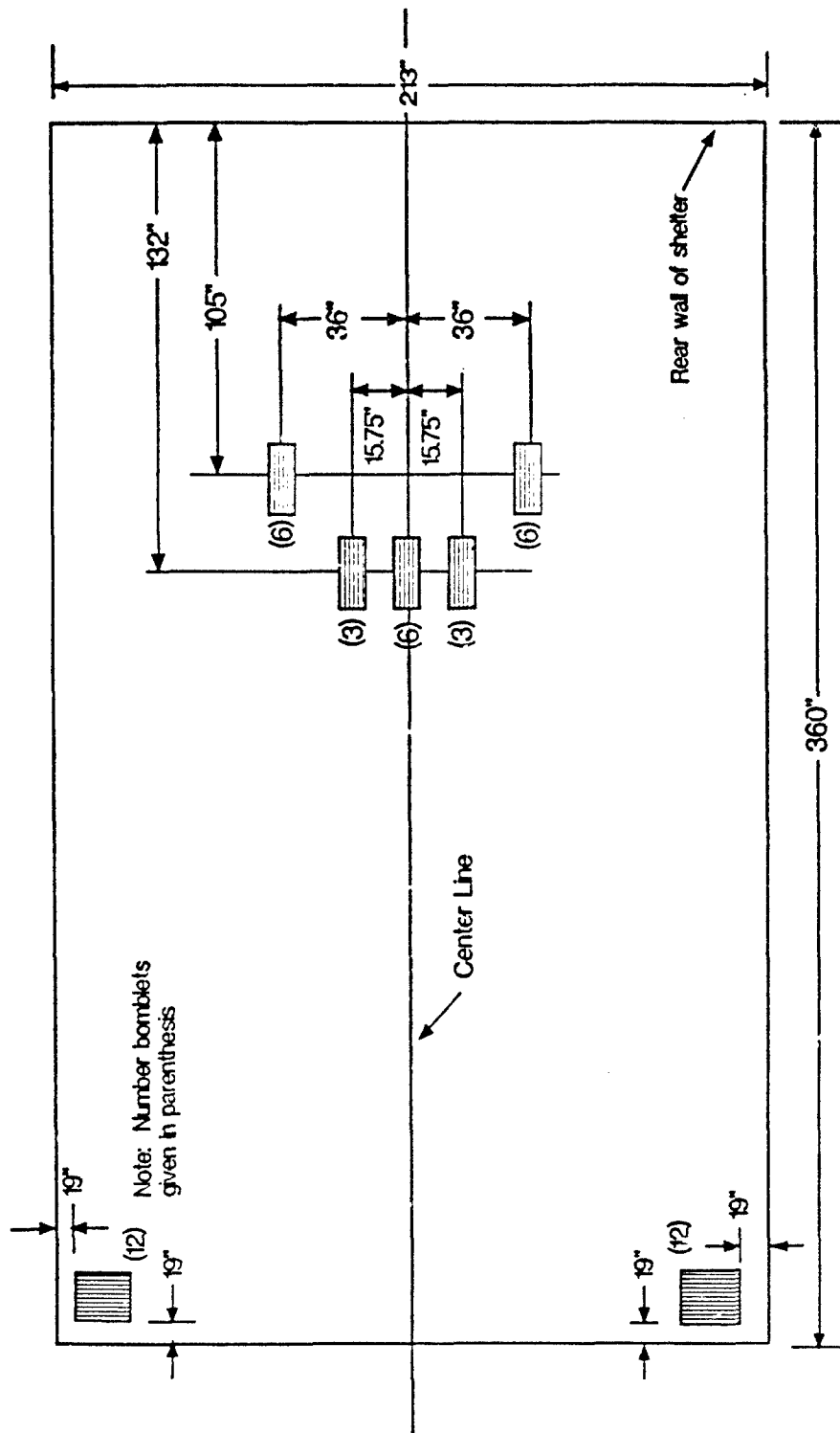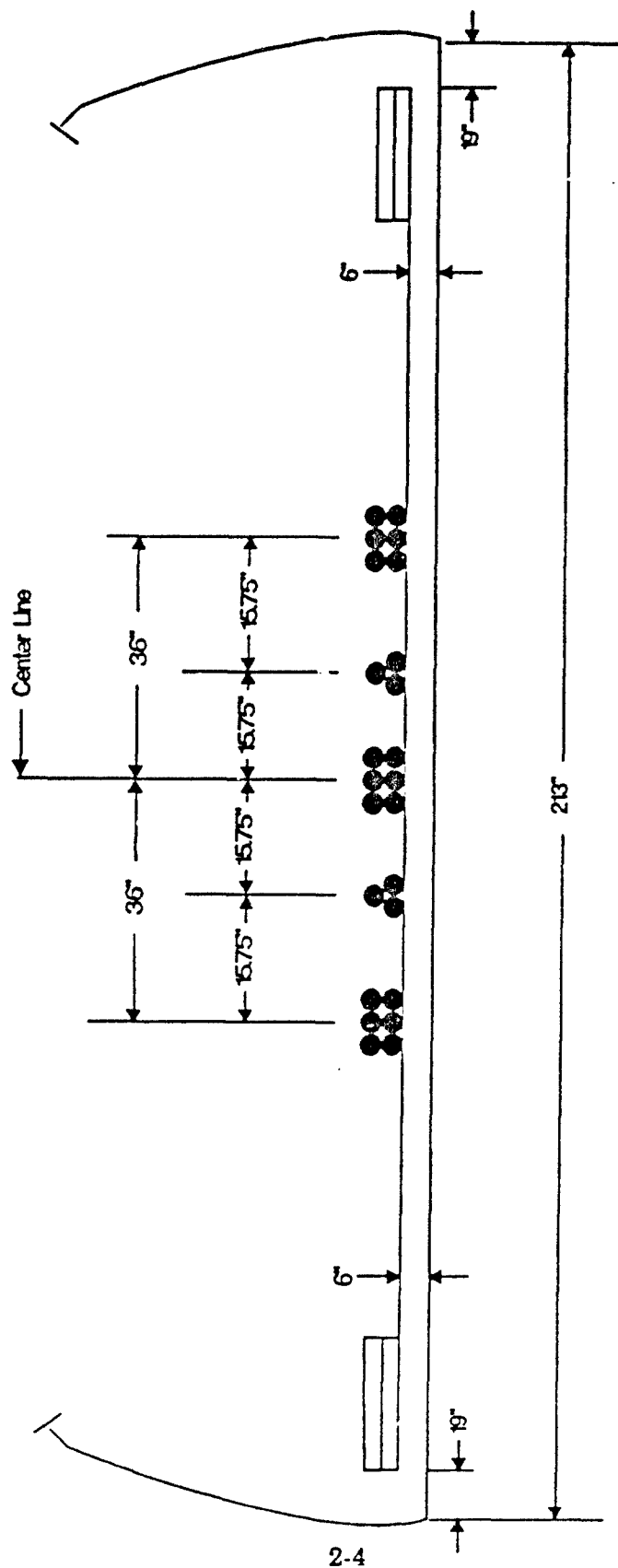FIGURE 2-1. PLAN VIEW OF QUARTER-SCALE MODEL SHOWING BOMBLET LOCATIONS

Note: Number bomblets given in parenthesis

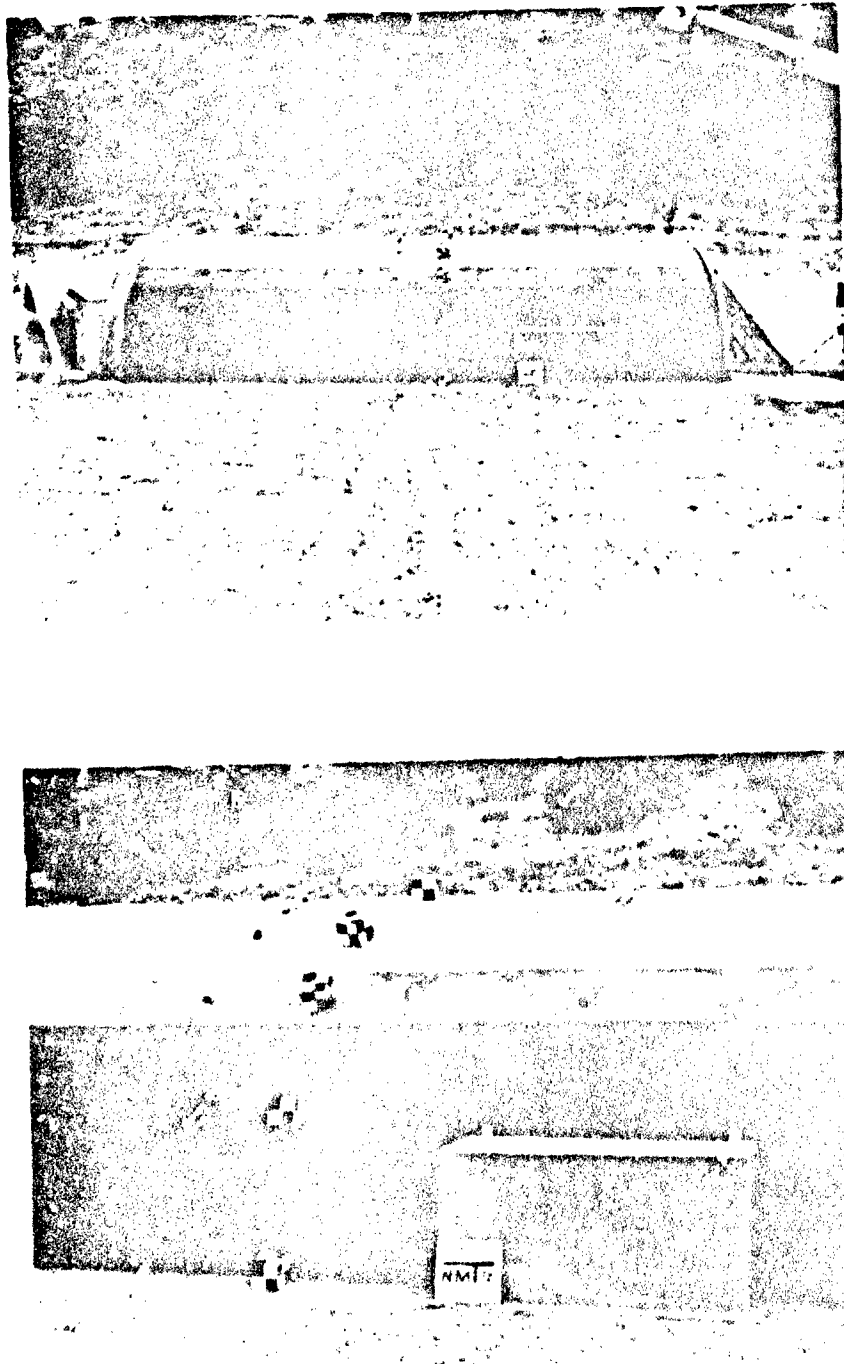FIGURE 2-2. FRONT VIEW OF QUARTER-SCALE MODEL SHOWING BOMBLET LOCATIONS
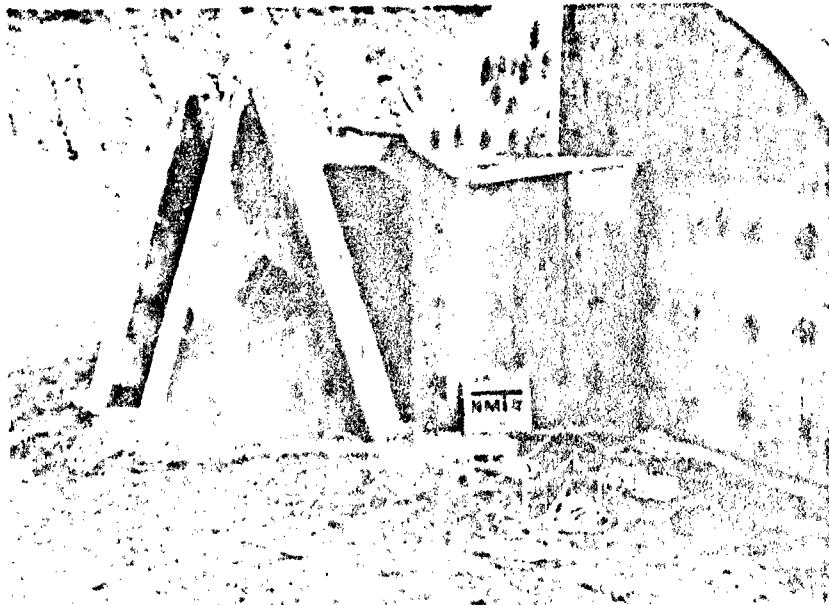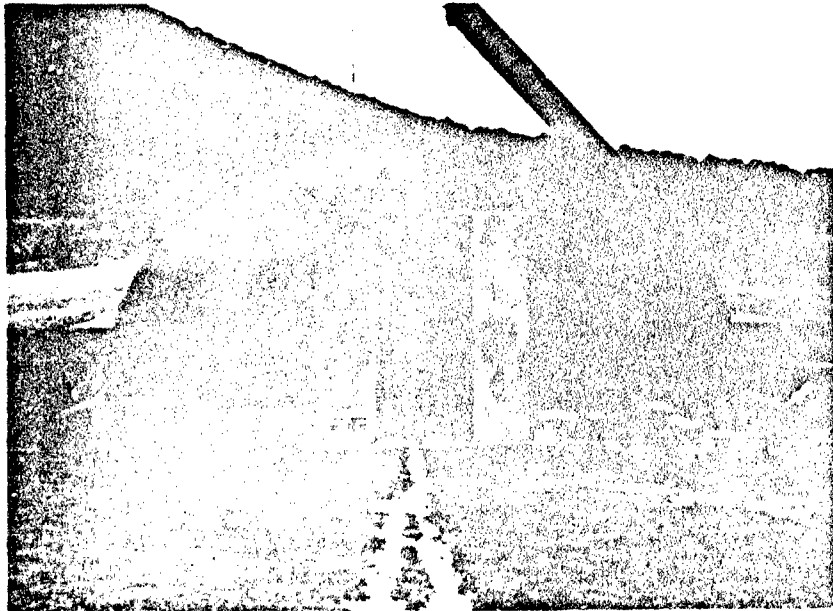
FIGURE 2-3. QUARTER SCALE MODEL, BEFORE DETONATION

FIGURE 2-3. (CONT)

CHAPTER 3

RESULTS AND OBSERVATIONS

GENERAL OBSERVATIONS

The test was conducted on 5 September 1990. A general impression of the observers present was that the model appeared to break up into larger pieces than had been expected. In fact, what appeared to be the entire side wall of the structure could be seen flying through the air. It must be pointed out, however, that this same phenomena was observed on DISTANT RUNNER Event 4. On that event, the side wall appeared to fly, wing-like, over the fiberboard fragment recovery bundles, landing in front of one of the high-speed cameras.

Figure 3-1 contains several views of post-test conditions. The first photograph shows the remains of the foundation after the detonation. From this view, it is evident that all of the stacks of bomblets appeared to detonate; i.e., there is a hole in the foundation corresponding to the location of each stack of bomblets.

On DISTANT RUNNER, the massive blast deflector remained relatively intact. For the modeling effort, the construction details were simplified. These simplifications did not seem to alter the results. The blast deflector remained a monolithic structure. This can be seen in Figure 3-1. Also, this figure shows other views of the debris remaining after the event.

Based on the final location of the pieces of the front door and an examination of the area surrounding their impact point, it can be concluded that the front door came off almost intact (two major pieces) and seemed to break up upon impact with the ground. It hit and stopped within the 5° recovery zone located out the front. (Note: the pieces were recovered within the 5° recovery sector.) If the door had been broken into more than a few large pieces before it was expelled from the shelter, the impact points would have shown a much greater dispersion.

After the event, the material located within the 5° recovery sectors was recovered, weighed, measured, and cataloged. In addition, over 160 pieces of large debris, located outside the 5° sectors, were also surveyed, recovered, and analyzed.

LARGE-SCALE DEBRIS

The size, location, and description of all of the recovered material is given in Reference 8. Figure 3-2 is a survey map of the large debris pieces which were located separately. Over 160 large pieces of debris are included in this category. In Reference 8, the front of the shelter is located at 0° (North), the recovery side of the shelter at 90° (East), and the rear at 180° (South). The 270° side faced a steeply up-sloping hill; thus, very little recovery effort was expended in this direction. If

Figure 3-2 is compared with similar maps generated for both the 1/10-scale (such as Figure 4-1 of Reference 6) and full-scale events (Figure 14 of Reference 3), no outstanding differences are apparent.

DISPLACEMENT CUBES

Prior to the event, a series of displacement cubes was placed on and around the outside of the structure. The reason for installing these cubes was twofold: (1) to act as debris of known size to be tracked photographically and (2) from their final locations and known initial starting points, to be able to back-calculate their launch velocity and angle.

There were two types of cubes used: (1) 2-inch aluminum cubes, weighing 0.75 pound each (a total of ten were used) and (2) 6-inch wooden cubes, weighing approximately 4.1 pounds each (a total of five were used). Figure 3-3 is a photograph showing several of these cubes in place on the shelter prior to the test. Figure 3-4 is a sketch of the locations of each of the cubes.

Out of the 15 cubes emplaced prior to the test, 13 were recovered afterward. One of the wooden cubes had broken into two pieces, but both pieces were recovered. Two of the aluminum cubes were never located. Table 3-1 gives the final locations of each of the cubes. None of the cubes could be seen in any of the high-speed photographic coverage. Using the information presented in Table 3-1 as well as the initial locations of the cubes, a series of trajectory calculations was performed to bracket the initial launch conditions required for the cubes to land where they were found. The computer program TRAJ9 was used for these calculations.

The sloping terrain present at the test site was included in the trajectory calculations. In addition, the ricochet option was enabled, with the soil being described as dry sand (soil constant = 2.00). For those cubes in direct contact with the side of the shelter, it was assumed that the launch angle was within ± 15 to $20°$ of the normal from the center of the shelter to the cube location. The results are shown in Table 3-2. Relatively low velocities were obtained, with consistent results being obtained from both types of cubes. It must be remembered that there is no unique combination of launch velocity and angle for a given final location—rather a range of angles and velocities.

With the exception of the cubes located on the very top of the structure, the velocities were all less than 200 ft/s. From the top of the structure, the velocities could be as high as 600 ft/s. However, based on information presented in Reference 6, an upper limit of 400 ft/s would seem to be more realistic.

PHOTOGRAPHIC COVERAGE

Because of weather conditions (overcast sky and intermittent rain), the high-speed photography was not very good. Only large pieces of debris could be resolved. The 6-inch wooden displacement cubes could not be seen in the high-speed films. In addition, it appears that a Wilson Cloud from condensation formed shortly after fireball breakout. This cloud tended to further obscure any of the early time close-in observations.

The photography indicates the detonation of the bomblet stacks inside the shelter (light appearing through the vent holes in the roof and around the openings for doors). Before any appreciable breakup or movement could occur, the entire scene is engulfed in flame and smoke. At very late times, approximately 100 msec or more after detonation, the large debris pieces emerge from the cloud/dust and can be tracked. Those debris pieces whose velocity could be determined are reported in Table 3-3. Again, the values are quite consistent with those obtained on the 1/10-scale model tests. It should be remembered that no velocity data was obtained on Event 5 of DISTANT RUNNER. On DISTANT RUNNER, the fireball obscured all useable data.

DEBRIS DATA BASE

Over 35,000 separate pieces of debris are reported and cataloged in Reference 7. However, only those pieces weighing over 30 grains (1.9 grams) were considered in the following analyses. Calculations performed for the analysis of both the full-scale DISTANT RUNNER and the 1/10-scale models showed that full-scale concrete debris must weigh at least 0.3 pound to be hazardous. A 1.9-gram debris piece from a 1/4-scale model would correspond to 121.6 grams (0.26 pound) full scale. Even after the lighter debris pieces were eliminated, there were approximately 19,000 debris pieces to be considered. The 1/4-scale debris data are available as ASCII files on computer disks upon request.
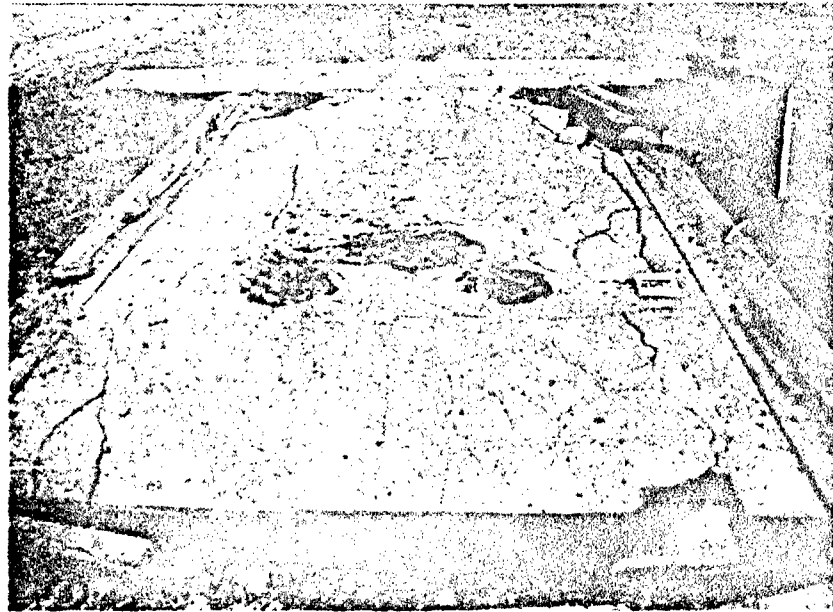
FIGURE 3-1. QUARTER-SCALE MODEL: AFTER DETONATION

FIGURE 3-1. (CONT.)
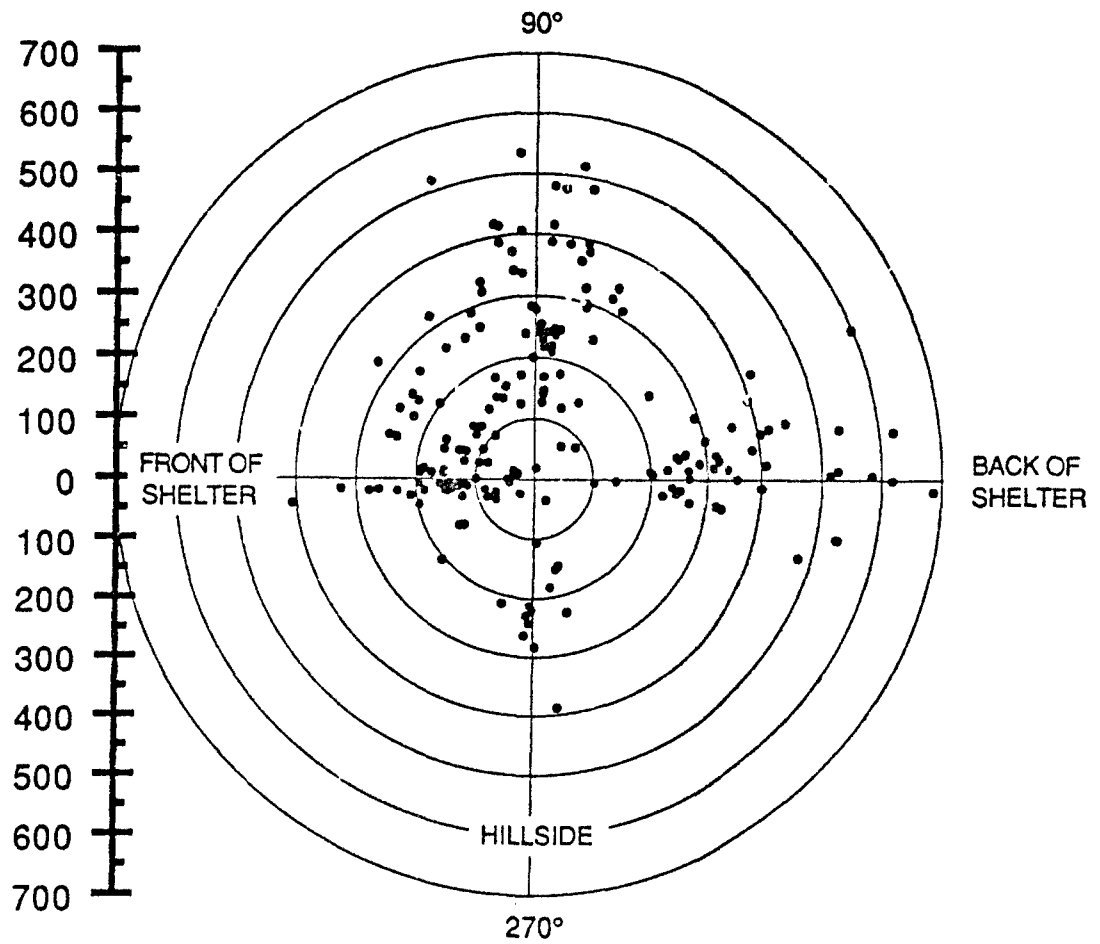
FIGURE 3-2. SURVEY MAP OF LARGE DEBRIS
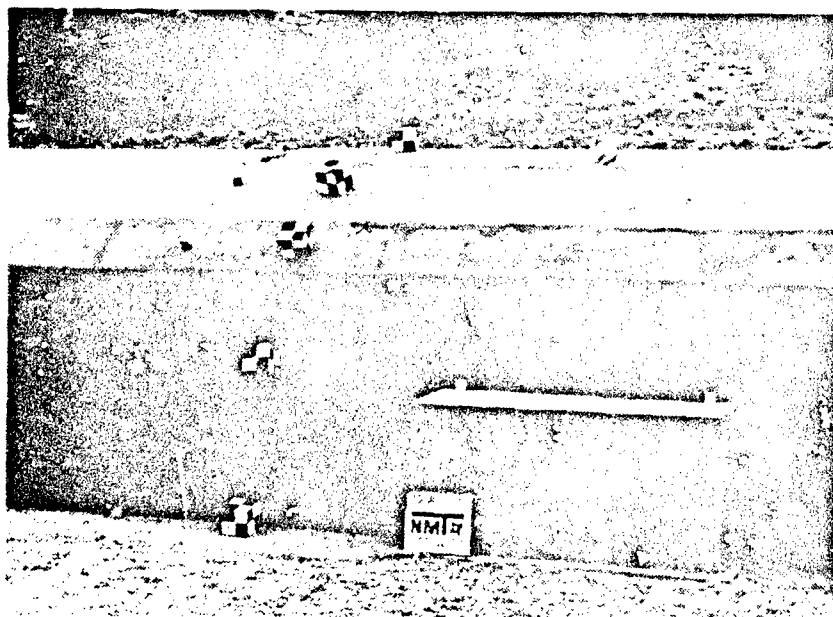
FIGURE 3-3. DISPLACEMENT CUBES ON MODEL
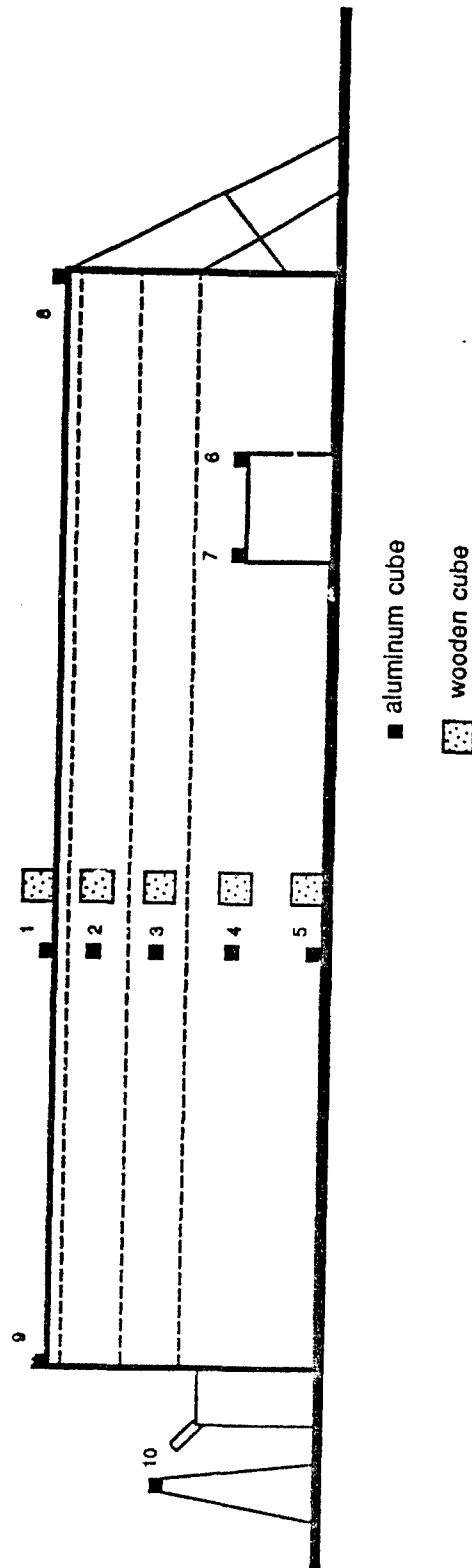
FIGURE 3-4. QUARTER-SCALE SHELTER: DISPLACEMENT CUBE LOCATIONS

TABLE 3-1. FINAL DISPLACEMENT CUBE LOCATIONS

| CUBE NUMBER | MATERIAL | DISTANCE | | HORIZONTAL |
		HORIZONTAL (FEET)	VERTICAL (FEET)	ANGLE (DEG.MIN.SEC)
AC-1	ALUMINUM	159.6	-10.03	107.55.44
AC-2	ALUMINUM	126.14	-6.29	100.42.03
AC-3	ALUMINUM	not located		
AC-4	ALUMINUM	277.61	-15.48	90.03.09
AC-5	ALUMINUM	241.59	-12.55	88.24.14
AC-6	ALUMINUM	229.2	-12.08	86.37.49
AC-7	ALUMINUM	220.73	-11.75	82.42.55
AC-8	ALUMINUM	not located		
AC-9	ALUMINUM	137.75	-10.05	123.35.46
AC-10	ALUMINUM	98.76	-1.59	179.14.11
W-1	WOOD	147.52		83.55.00
W-2	WOOD	199.5	-10.36	91.07.00
W-2A	WOOD	169.02	-8.88	85.08.40
W-3	WOOD	248.55	-13.01	82.27.43
W-4	WOOD	254.09	-12.96	87.31.55
W-5	WOOD	211.31	-11.41	82.33.00

NOTES:

(1) Distances and angles are measured relative to the center of the shelter

(2) 0° is out the front of the shelter

(3) Because of the sloping terrain, the vertical displacements
    are included

TABLE 3-2. INITIAL CONDITIONS DETERMINED FROM DISPLACEMENT CUBE LOCATIONS

MATERIAL	IDENTIFICATION NUMBER	INITIAL HEIGHT (feet)	INITIAL ANGLE (°)	FINAL RANGE (feet)	LAUNCH ANGLE (°)	LAUNCH VELOCITY (ft/s)
Aluminum	5	0.2	0	242	5–10	130-160
Wood	5	0.2	0	211	1–9	130-160
Aluminum	4	2.5	15	278	0-14	130-160
Wood	4	2.5	15	254	10–25	120-160
Aluminum	3	6.6	35	not found	not calculated	not calculated
Wood	3	6.6	35	249	30-40	90-120
					10–20	130-150
Aluminum	2	7	50	126	30-70	60-80
Wood	2	7	50	broken	not calculated	not calculated
Aluminum	1	7.5	90	160	81-85	200-250
					85-87	250-400
					86-87	450-600
Wood	1	7.5	90	148	72-82	140-160
					78-84	180-200
					81-85	250-300
					83-88	300-500
Aluminum	6,7	2	15	229 & 221	12–18	110-130
					10 to -6	130-150
Aluminum	8	7.5	90	not found	not calculated	not calculated
Aluminum	9	7.5	90	138	30-50	50-70
					72-78	90-110
					76-78	110-130
					78-84	130-150
					80-84	150-170
					82-85	170-190
					82-86	190-210
Aluminum	10	4	45	99	20-60	50-70
					10–20	70-90

TABLE 3-3. PHOTOGRAPHICALLY-DETERMINED DEBRIS VELOCITIES

TYPE OF MATERIAL	VELOCITY (ft/s)	TENTH-SCALE (ft/s)
Large/Side wall	56-80	118
off side	84	60-260
off side	90	60-260

NOTES:
  (1) relatively few fragments were obervable on the films
  (2) no velocities were measured for DISTANT RUNNER Event 5

CHAPTER 4

BREAK-UP ANALYSIS

As mentioned above, one of the important questions raised after the 1/10-scale tests was, "Did the structure break up into larger pieces than expected?" This chapter will attempt to answer that question.

An apparent scale factor can be determined by any of several methods. This section will present the results of one such analysis—based upon debris length. Since the length is dependent upon the debris shape, a measure of the shape of each debris piece, called the Shape Factor, will also be discussed.

SHAPE FACTOR

Portions of the concrete debris collected in the 5° recovery areas were evaluated as to shape factor. The shape factor relates the debris weight with a length dimension according the relationship:

$$M = B^*\rho_c^*L^3 \qquad (1)$$

where:

M = debris mass or weight
B = shape factor
ρ_c = concrete density, nominally 150 lb/ft^3
L = (debris length x debris width x debris thickness)$^{1/3}$

The shape factor represents the fraction of the volume of the box determined by the debris, when that box is filled by the debris of mass M with density ρ_c. Note that the dimensions (length, width, thickness) specify a box size within which the debris item can just fit. This is shown schematically in Figure 4-1.

Samples were selected from all three directions and statistically analyzed for shape factor. The complete analysis of these samples is reported in Reference 10. Samples from each direction were separated according to sieve size (0.25", 0.375", 0.50", 0.75",and 1.00" sieve mesh), weighed, measured, and shape factor determined. Figure 4-2 shows the results of these analyses. For each direction, the average shape factor was 0.38. When the data are combined, an estimate of the shape factor for the 1/4-scale model can be established. This is 0.38 ± 0.06, based on 4,478 samples. The average value obtained for DISTANT RUNNER was 0.44 ± 0.03 (based on 5,837 samples); that for the 1/10-scale models was 0.47 ± 0.03 (based on a total of over 22,000 pieces for the five models).

The differences between the 1/10-scale and the full-scale are statistically significant (at the 95 percent confidence level), as was pointed out in Reference 6. A

similar, statistically significant, difference between the 1/4-scale and the full-scale results was also found. The effect of these differences is to contribute to the overestimation of debris ranges based on the 1/10- and 1/4-scale results.

CHARACTERISTIC LENGTH

During the original analysis of the 1/10-scale shelter data, one of the authors, Dr. William Soper, proposed sorting the debris data in the following manner: the number of debris pieces per weight interval versus debris weight—with everything scaled to full scale. Table 4-1, taken from Reference 6, presents this original data. This table has now been expanded to include the 1/4-scale data, with the results presented in Table 4-2.

Using Equation (1), a debris length can be computed for the mid-point of each weight interval shown in Table 4-2. With this information, the data in Table 4-2 can be converted into a chart of debris length versus debris number.

Porzel, in his development of the Technology Base for the Naval Explosives Safety Improvement Program,[11] postulated the following number distribution for the breakup of materials:

$$N(>L) = N_0 e^{(L/LBAR)} \tag{2}$$

where:

$N(>L)$ = number of debris pieces with length greater than L
N_0 = total number of debris pieces (determined by fit)
L = debris length
$LBAR$ = characteristic debris length, in same units as L (determined by fit)

This distribution has been applied to the fragmentation or breakup of a wide variety of items including primary fragments from bomb cases following a detonation, pieces of a broken dinnerware plate, and sizes/numbers of pieces of naturally occurring coal.

In Reference 3, this distribution was applied to the data generated on Events 4 and 5 of DISTANT RUNNER. It was observed in this case that there appeared to be at least two characteristic sizes of the debris rather than one, and the technique was not pursued further.

Figure 4-3 illustrates a typical example and the application of Equation (2). At least two break points are identified. Their location is chosen to maximize the correlation coefficient obtained fitting Equation (2) to a portion of the data. One curve is fitted to the data below Break 1; a second equation is fitted to the data lying between the first and second break. The values of LBAR obtained in each portion as well as the location of the break points themselves can then be compared to determine appropriate values of scale factor. For example, let us assume (arbitrarily) that an LBAR of 1.65 inches was obtained for the full-scale results and an LBAR of 0.50 inch for the nominal 1/4-scale. Then the apparent scale factor is simply 1.65/0.50 or 3.30. Similarly, let us assume that the first break point occurred at 7.5 inches full scale and 2.5 inches, 1/4-scale. In this instance, the apparent scale factor is 7.5/2.5 or 3.0. The location of the second break point could, theoretically, be used to determine an apparent scale factor. However, because of the smaller amount of data available in this portion of the distribution, the results may not be as accurate.

Figures 4-3, 4-4, and 4-5 present the debris-number distributions, based on debris length, obtained for the three scale sizes: full-scale, 1/10-scale, and 1/4-scale. The full-scale distribution, Figure 4-3, differs slightly from the one appearing in Reference 3. Additional data were added to the distribution, small errors were corrected, and the results recalculated for this report. Table 4-3 presents a summary of the apparent model scale factors based upon this method. For the 1/10-scale model, the apparent scale factor varied between 7.405 and 9.5, with an average of 8.660. The 1/4-scale apparent scale factor varied between 3.00 and 4.01, with an average of 3.418.
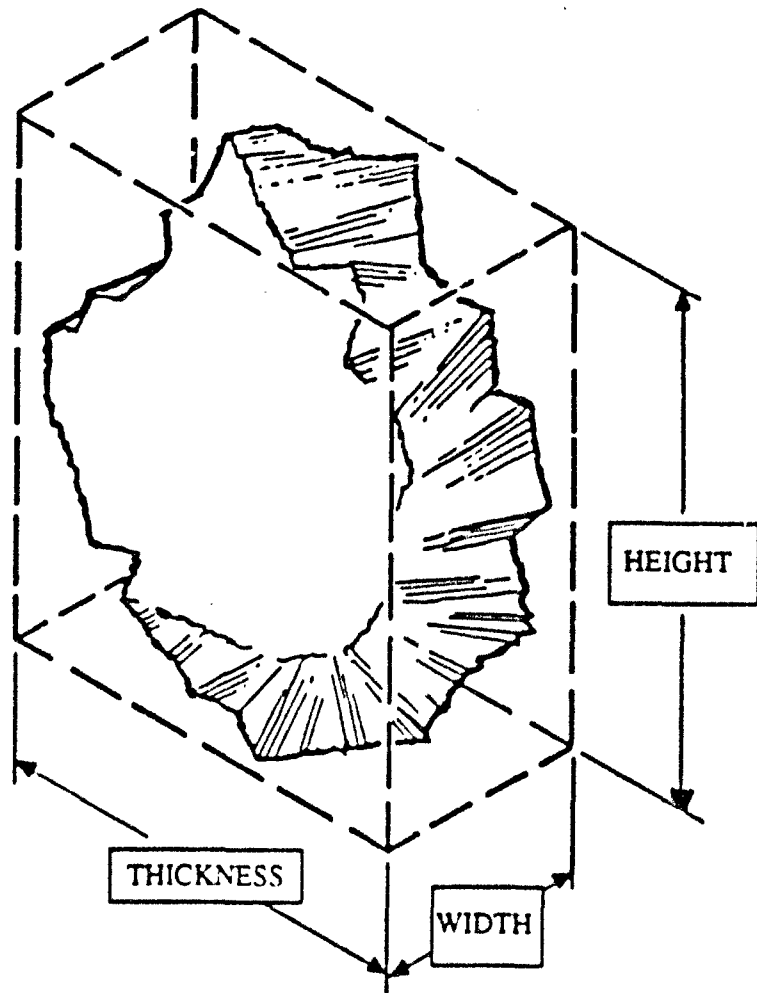
FIGURE 4-1. SHAPE FACTOR MEASUREMENTS

FRONT

SIDE
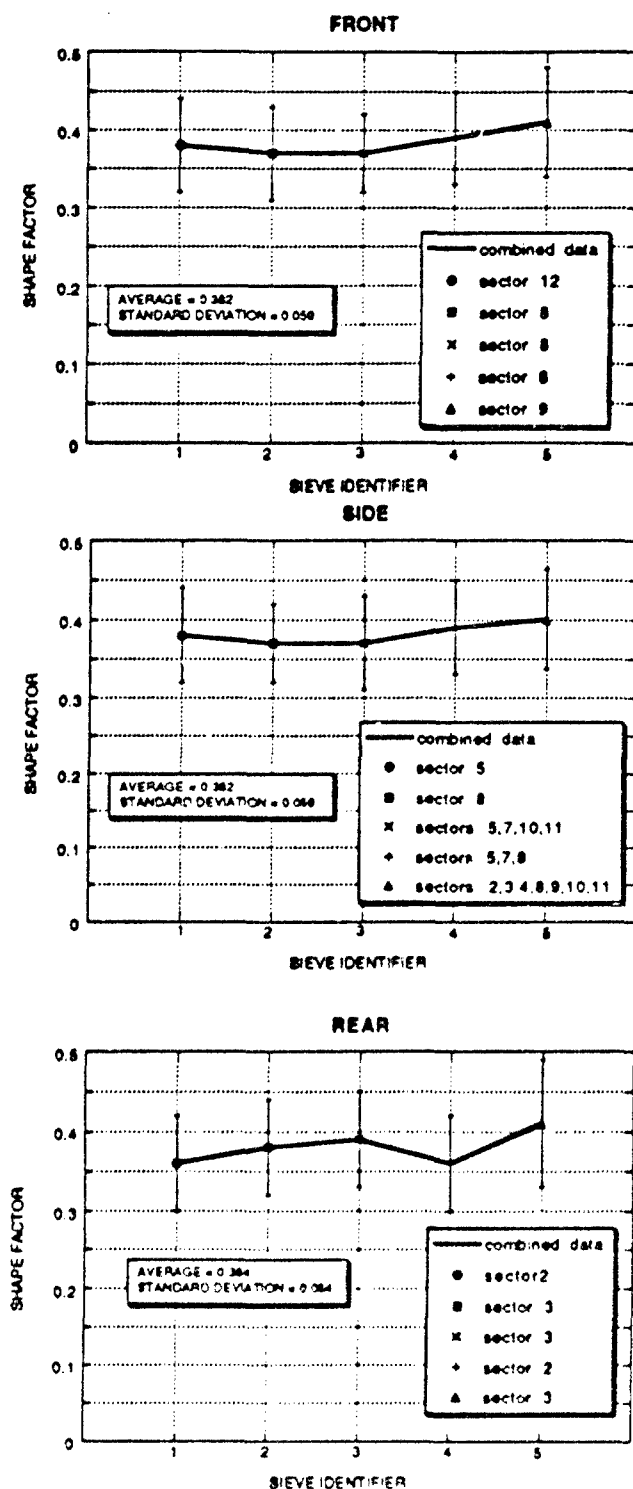
SIEVE IDENTIFIER:
1: 0.25"
2: 0.375"
3: 0.50"
4: 0.75"
5: 1.00"

REAR

FIGURE 4-2 QUARTER-SCALE SHAPE FACTOR COMPARISONS

4-5
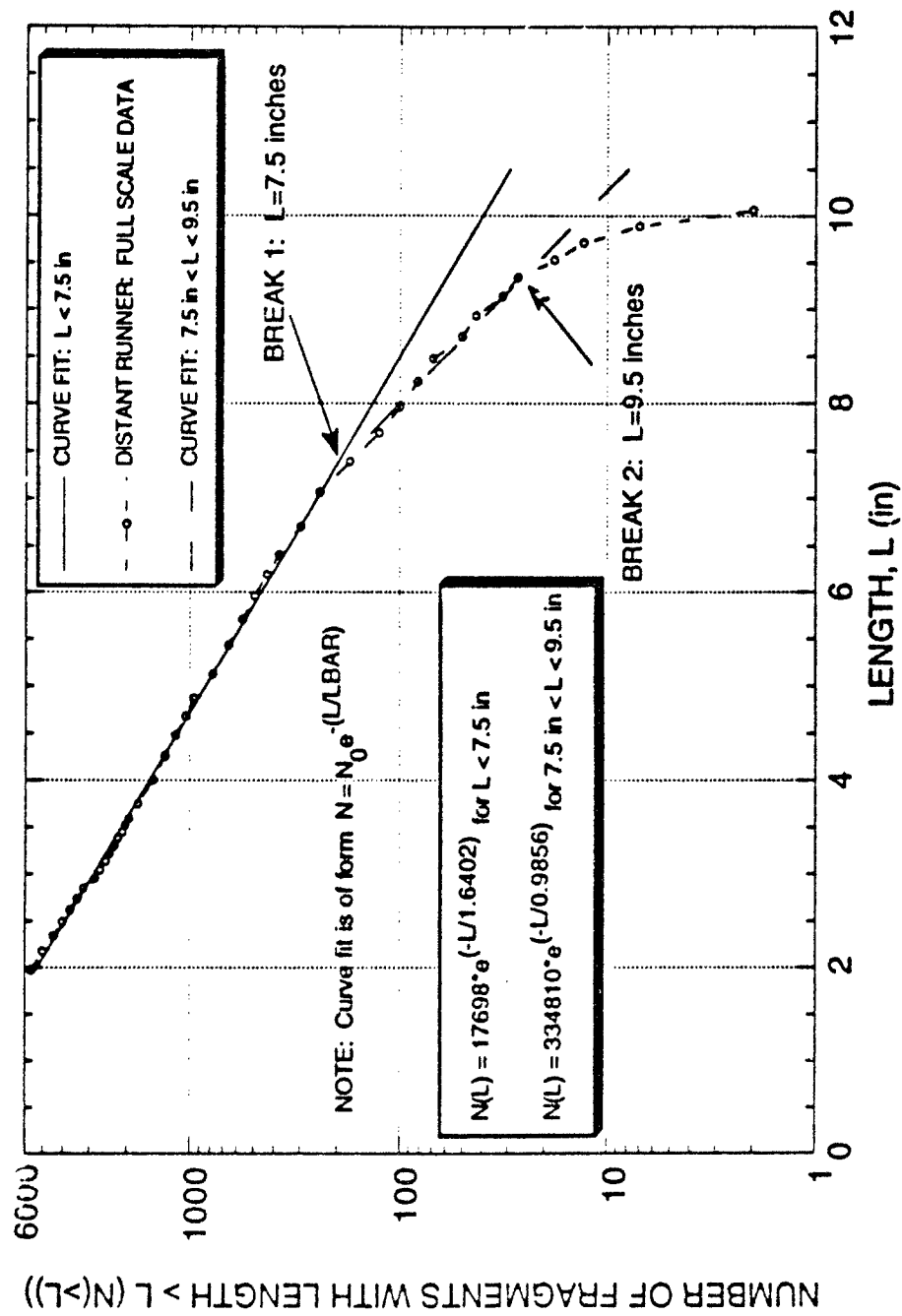
FIGURE 4-3. DEBRIS-NUMBER DISTRIBUTION: DISTANT RUNNER (FULL SCALE)
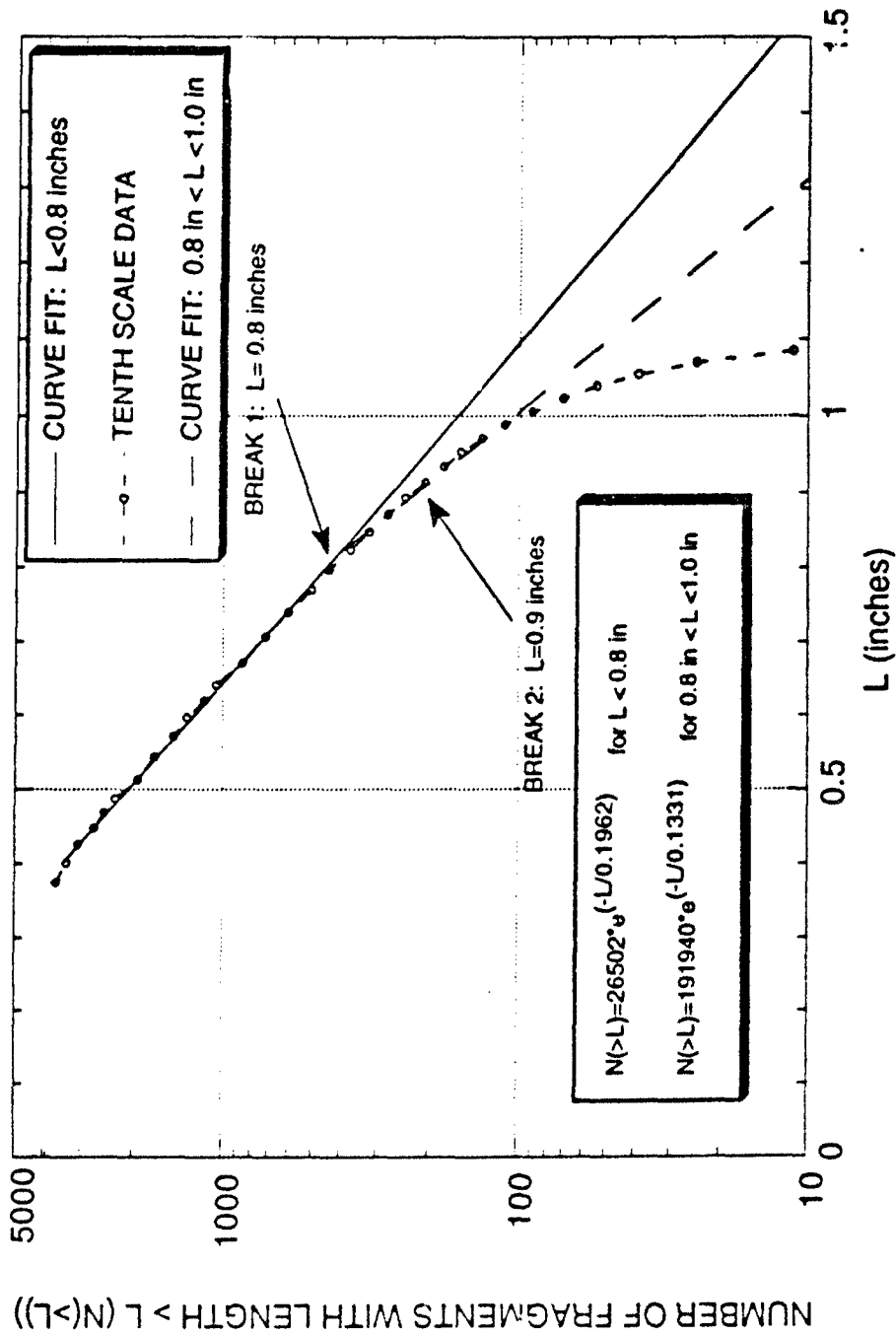
FIGURE 4-4. DEBRIS-NUMBER DISTRIBUTION: TENTH-SCALE MODELS
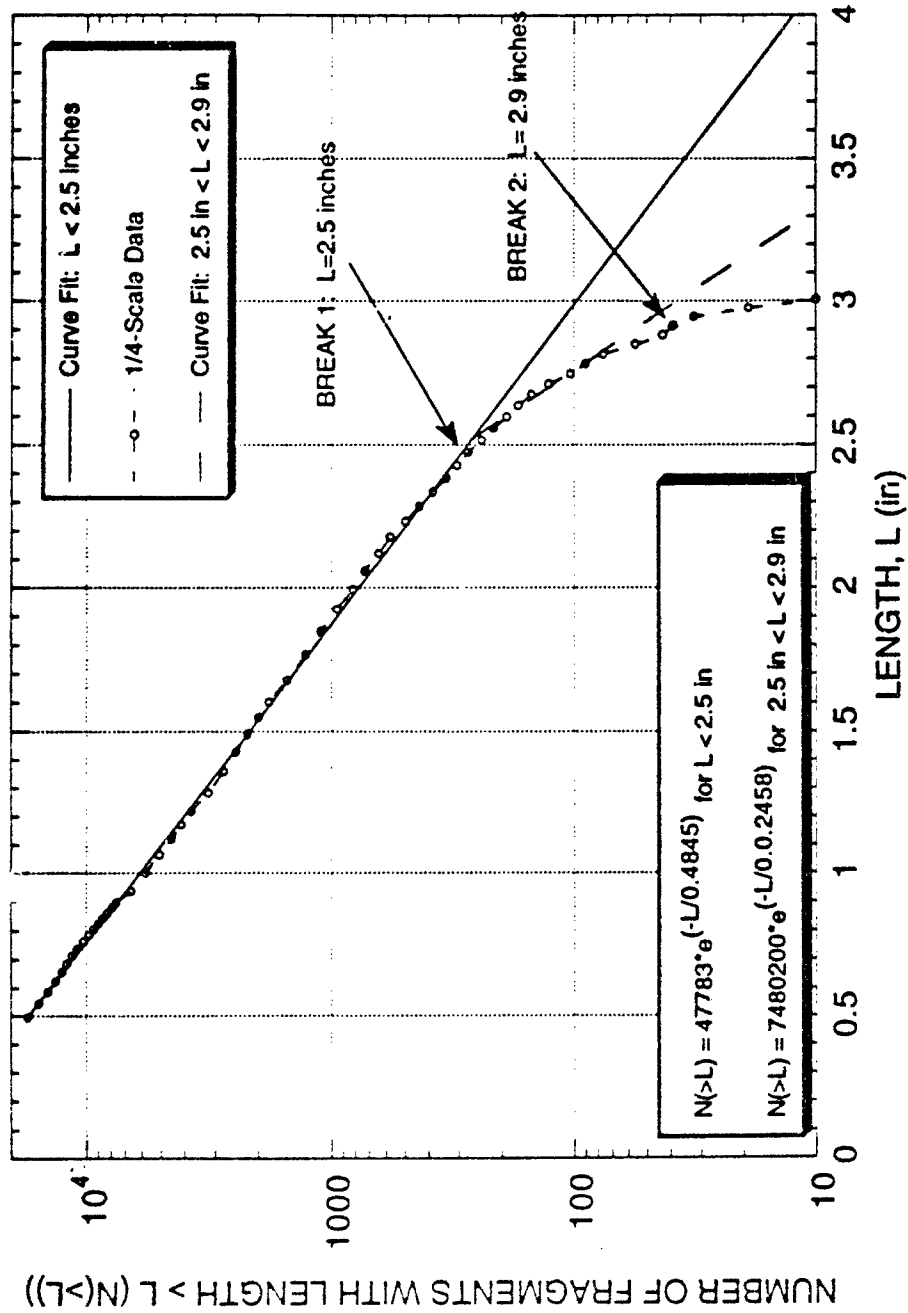
FIGURE 4-5. DEBRIS-NUMBER DISTRIBUTION: QUARTER-SCALE MODELS

TABLE 4-1. DISTANT RUNNER AND TENTH-SCALE MODEL MASS DISTRIBUTIONS

WEIGHT INTERVAL		DISTANT RUNNER	TENTH SCALE
W1 (lbs)	W2 (lbs)	NUMBER	NUMBER
0.25	0.35	169	
0.35	0.45	642	
0.45	0.55	558	
0.55	0.65	390	
0.65	0.75	324	
0.75	0.85	280	
0.85	0.95	213	
0.95	1.15	363	
1.15	1.25	166	
1.25	1.35	149	
1.35	1.45	120	
1.45	1.55	101	
1.55	1.65	101	
1.65	1.75	93	
1.75	1.85	74	
1.85	2.25	260	218.4
2.25	2.75	262	265.6
2.75	3.25	177	286.2
3.25	3.75	140	360
3.75	4.25	124	209.6
4.25	4.75	89	198.8
4.75	5.75	173	368.6
5.75	6.75	125	228.2
6.75	7.75	95	232.4
7.75	8.75	70	147.2
8.75	9.75	62	162.8
9.75	10.75	52	104
10.75	12.75	79	192.2
12.75	14.75	57	142.4
14.75	16.75		115.6
16.75	18.75		100.6
18.75	20.75		65.6
20.75	22.75		67.8
22.75	24.75		49.4
24.75	26.75		44.6
26.75	28.75		35.2
28.75	30.75		33.8
30.75	32.75		29.2
32.75	34.75		22.8
34.75	36.75		24
36.75	38.75		21.6
38.75	40.75		21.8
40.75	42.75		19.4
42.75	44.75		16.4
44.75	46.75		15.6
46.75	48.75		14.8
48.75	50.75		13.2
50.75	52.75		11.2

NOTES:
(1) DISTANT RUNNER is Event 5
(2) TENTH SCALE is average of five events

TABLE 4-2. MASS DISTRIBUTIONS

WEIGHT INTERVAL		DISTANT RUNNER	TENTH SCALE	QUARTER SCALE
W1 (lbs)	W2 (lbs)	NUMBER	NUMBER	NUMBER
0.25	0.35	169		1762
0.35	0.45	642		1663
0.45	0.55	558		1274
0.55	0.65	390		103C
0.65	0.75	324		750
0.75	0.85	280		546
0.85	0.95	213		588
0.95	1.15	363		1076
1.15	1.25	166		477
1.25	1.35	149		424
1.35	1.45	120		406
1.45	1.55	101		363
1.55	1.65	101		344
1.65	1.75	93		335
1.75	1.85	74		268
1.85	2.25	260	218.4	975
2.25	2.75	262	265.6	866
2.75	3.25	177	286.2	681
3.25	3.75	149	360	532
3.75	4.25	124	209.6	408
4.25	4.75	89	198.8	378
4.75	5.75	173	368.6	565
5.75	6.75	125	228.2	413
6.75	7.75	95	232.4	295
7.75	8.75	70	147.2	256
8.75	9.75	62	162.8	218
9.75	10.75	52	134	189
10.75	12.75	79	192.2	283
12.75	14.75	57	142.4	244
14.75	16.75		115.6	172
16.75	18.75		100.6	160
18.75	20.75		85.6	130
20.75	22.75		67.8	89
22.75	24.75		49.4	90
24.75	26.75		44.6	65
26.75	28.75		35.2	78
28.75	30.75		33.8	60
30.75	32.75		29.2	54
32.75	34.75		22.8	45
34.75	36.75		24	33
36.75	38.75		21.6	31
38.75	40.75		21.8	33
40.75	42.75		19.4	26
42.75	44.75		16.4	25
44.75	46.75		15.6	20
46.75	48.75		14.8	19
48.75	50.75		13.2	23
50.75	52.75		11.2	24

NOTES:
(1) DISTANT RUNNER is Event 5
(2) TENTH SCALE is average of five events

TABLE 4-3. AIRCRAFT SHELTER SCALE FACTOR DETERMINATION BASED ON LENGTH DISTRIBUTION

EVENT	MEASUREMENT								
	LBAR-1 (in)	SCALE FACTOR	LBAR 2 (in)	SCALE FACTOR	BREAK 1 (in)	SCALE FACTOR	BREAK 2 (in)	SCALE FACTOR	AVERAGE
DISTANT RUNNER	1.6402	1.000	0.9856	1.000	7.5	1.000	9.5	1.000	
TENTH SCALE	0.1962	8.360	0.1331	7.405	0.8	9.375	1	9.500	8.660
QUARTER SCALE	0.4845	3.385	0.2458	4.010	2.5	3.000	2.9	3.276	3.418

CHAPTER 5

HAZARD RANGES

The debris ranges obtained from the model results must be scaled to full scale before hazard ranges can be computed. Unfortunately, the scaling of debris ranges is not straightforward since gravity was not scaled in the model experiments. A scaling algorithm was developed and reported in Reference 6. Essentially, given the location of each piece of debris in the model scale, estimates are made of the launch conditions required to place it at that location. The debris piece is then scaled to full scale, the previously-calculated launch conditions applied, and the "full-scale" debris trajectory is calculated. This is repeated for each debris piece. As indicated above, the algorithm is detailed in Reference 6. As a check on the algorithm, the procedure was applied to the full-scale DISTANT RUNNER results. If the procedure is working appropriately, the same debris locations as the input conditions should be returned when the algorithm is applied. This was, indeed, the case.

Certain assumptions and information are required before the algorithm can be applied. These include the densities and shape factors of the debris. In addition, a debris cut-off velocity must be specified. When a piece of debris impacts the ground and breaks up into smaller pieces, one result is an unrealistic estimate for the initial velocity of the intact piece. When the calculated initial debris velocity exceeds this specified value, that particular piece of debris is not considered further. A value of 400 ft/s has been used in all of these debris analyses. This value is consistent with both the photographically-determined and the displacement cube-inferred velocities previously reported.

Since the debris analyses were performed and reported in References 3 to 7, additional work[12,13] has been performed on the standardization of such analyses. One important difference is the calculation of a pseudo-trajectory normal (PTN) hazardous fragment density. These new techniques have been applied to the original DISTANT RUNNER Event 5 data as well as to the data from the five 1/10-scale models. The results are shown in Table 5-1. The ranges were only slightly different using both the old and the newer, preferred technique. The 1/4-scale results are very similar to the full-scale DISTANT RUNNER results out the side and the rear, but are significantly longer out the front. Out the front, the 1/4-scale results more closely resemble the 1/10-scale results.

On both the 1/10-scale and 1/4-scale models, the front door assembly hit within the recovery sector bounced and broke up. On the full-scale event, the door landed outside the 5° recovery sector. This would help to explain why the hazard range in the direction to the front of all of the models was significantly greater than the DISTANT RUNNER range.

TABLE 5-1. COMPARISON OF MODEL DATA WITH FULL-SCALE HAZARD RANGES

EVENT	HAZARD RANGE (m/kg^1/3)		
	FRONT	SIDE	REAR
DISTANT RUNNER (OLD)	19.6	24.5	15.3
DISTANT RUNNER (PTN)	**20.1**	**21.4**	**17.3**
TENTH SCALE-1 (OLD)	26.88	28.15	18.38
TENTH SCALE-2 (OLD)	26.29	26.93	19.73
TENTH SCALE-3 (OLD)	24.90	30.17	15.41
TENTH SCALE-4 (OLD)	25.61	27.16	18.02
TENTH SCALE-5 (OLD)	25.90	27.99	20.49
TENTH SCALE-AVERAGE (OLD)	**25.9**	**28.1**	**18.4**
TENTH SCALE-1 (PTN)	25.93	27.29	20.00
TENTH SCALE-2 (PTN)	26.63	28.22	21.36
TENTH SCALE-3 (PTN)	27.18	32.22	16.79
TENTH SCALE-4 (PTN)	22.72	26.61	19.26
TENTH SCALE-5 (PTN)	28.66	30.44	22.71
TENTH SCALE-AVERAGE (PTN)	**26.2**	**29.0**	**20.0**
QUARTER SCALE (PTN)	**26.9**	**22.4**	**15.0**

NOTES:
(1) PTN is Pseudo Trajectory Normal Density
(2) OLD is the previous method of calculating debris density

CHAPTER 6

SUMMARY

Three distinct sizes of reinforced concrete structures have now been constructed and tested to destruction: (1) DISTANT RUNNER at full scale, (2) a series of five 1/10-scale models, and (3) one 1/4-scale model. In the most general terms, all three behaved in a similar manner.

One objective of the model testing is to determine if the hazard ranges can be inferred from the model results. DISTANT RUNNER showed that the explosives safety quantity-distance (ESQD) range for these third-generation hardened aircraft shelters was controlled by the debris/fragmentation rather than airblast. The series of 1/10-scale model tests showed that the full-scale airblast results were, indeed, adequately predictable from these model data. Because of this and because the airblast did not drive the ESQD range, airblast was not measured on the 1/4-scale test.

The 1/10-scale models overpredicted the debris hazard range in all three directions. The 1/4-scale model agreed with the full-scale results off the side, slightly underpredicted them off the rear, and overpredicted them out the front. One reason both the 1/10- and 1/4-scale models overpredicted the range out the front is because of the behavior of the front door. At full scale, the doors seemed to hold together and landed outside the recovery sectors, not influencing the debris density for the front recovery sector. On both model scales, the doors landed within the recovery sectors and partially broke up.

At the 95 percent confidence level, the shape of the recovered debris (as measured by the debris shape factor) for both the 1/10- and 1/4-scale results, was statistically different from the full-scale results.

Another objective of this program was to examine the relationship between the "design-scale" of a model and its "apparent-scale," as determined from its breakup behavior. The apparent scale factor; i.e., the scale factor inferred from experimental data, was less than the design scale factor for both model scales. At 1/10-scale, the average apparent scale factor (as determined by the length distribution) was 8.66 rather than 10. At 1/4-scale, the factor was 3.42. Figure 6-1 presents this relationship as determined for the reinforced concrete structures tested during this program. A caveat must be applied here. Only this one type of structure has been considered. The relationship shown in Figure 6-1 may not apply to another type of structure or to a similar structure if significant changes are made in the way in which the structure is modeled.

These series of tests have indicated that the break-up behavior of reinforced concrete structures can be inferred from model results. The gross break-up pattern is similar. The shape factors are nearly identical. The hazard ranges mirror the full-scale numbers.
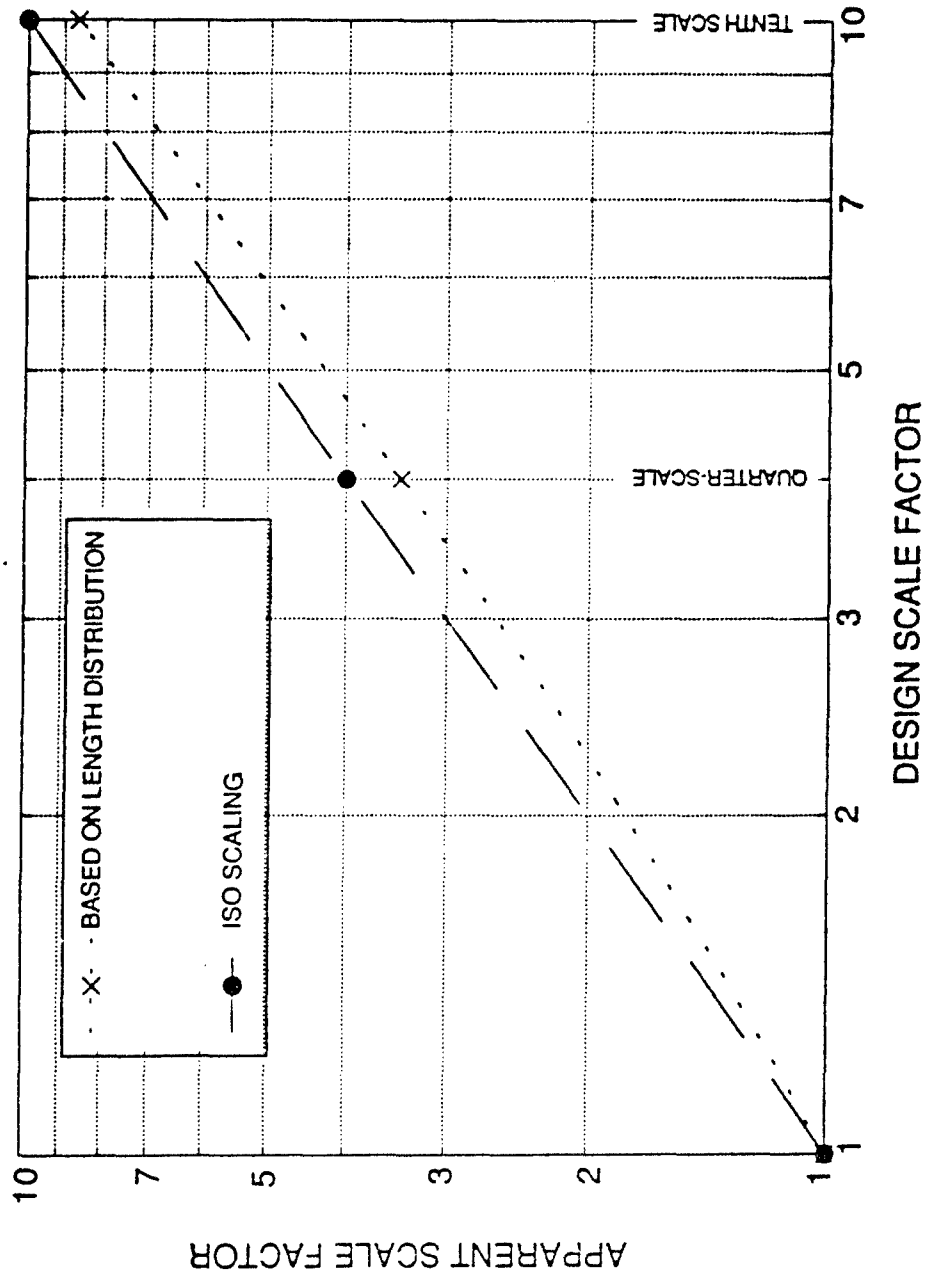
FIGURE 6-1. DESIGN VERSUS APPARENT SCALE FACTOR

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13. ABSTRACT *(Maximum 200 words)*

Operation DISTANT RUNNER produced data on the size and distribution of both airblast and debris produced by the detonation of 4500 kilograms of high explosive inside a Third Generation Hardened Aircraft Shelter. DISTANT RUNNER also produced data on the fragment/debris hazard ranges which are associated with detonations inside the shelter. After the full-scale tests were completed, that event was modeled at two scales 1:10 and 1:4. These structures used detailed geometric modeling of both the rebar and the aggregate with which the reinforced structure was built. The concrete mixture, however, was modeled for the full-scale compressive strength.

The 1:10 size model appeared to behave as if it were more like a 1:7 scale model. This appeared in the airblast, the size and distribution of the debris, and the hazard ranges produced by the debris. Because of this, testing at a larger scale was undertaken.

This report presents the results of breakup and debris throw for a quarter-scale shelter. Results obtained from all three scales are also compared. For the structure modeled in these tests and with the decisions which were made about the details of the modeling used, the apparent scale factor (as determined from the breakup of the structure) differs from the design scale factor. As the scale size becomes larger (i.e., smaller models), the differences between design and apparent scale factor increases.

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Aircraft Shelter	Concrete		
Modeling	Scaling		16. PRICE CODE
Breakup			

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
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